ExEP Resources for Technology Demonstrations at JPL

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Pre-Proposal TDEM-14 Briefing Telecon
01/20/15

ExEP Resources for Technology Demonstrations

- **This presentation provides an overview of the ExEP resources located at JPL available to support a TDEM-14 proposal.**

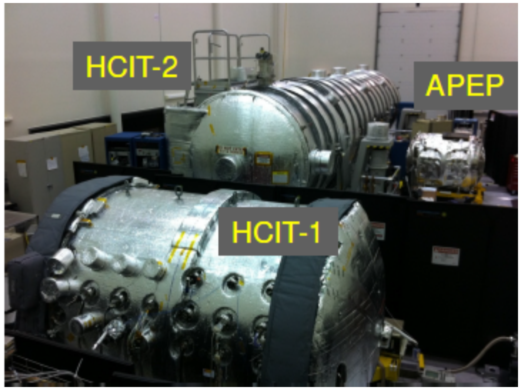
- **The available resources, if appropriate for your needs, may help you more efficiently meet your milestone goals and reduce your proposal costs and schedule.**

Unavailable Resources at JPL for TDEM-14

- High Contrast Imaging Testbeds (HCIT-1 and -2)
- Wavefront Sensing & Control

Available Resources at JPL for TDEM-14

- Apep Vacuum Chamber
- Vacuum Surface Gauge
- Coronagraph Modeling and Error Budgeting
- Microdevices Laboratory (MDL)
- Starshade Deployable Testbed (new)
- Large deployable structures lab
- Scatterometer
- Mach-Zender interferometer

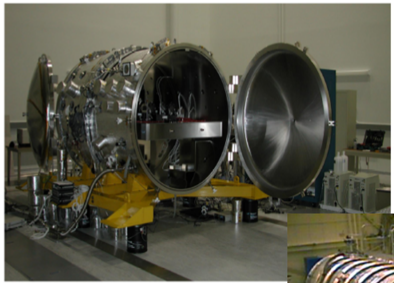


Unavailable Resources at JPL for TDEM-14

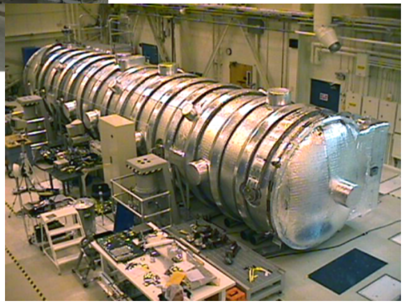
High Contrast Imaging Testbeds (HCITs)

Test Facility

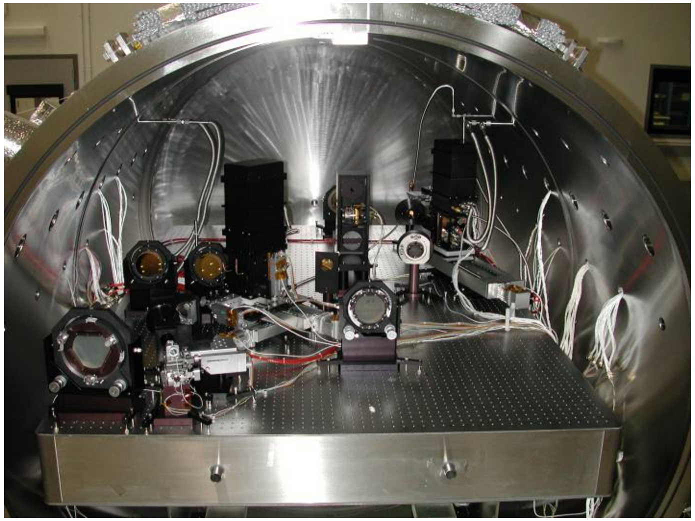
- Two vacuum chambers with 1 mTorr capability
- Seismically isolated, temperature-stabilized ~ 10 mK at RT.
- Narrow or broad band coronagraph system demos
  - Achieved $3x10^{-10}$ contrast (narrowband)
- Fiber/Pinhole "Star" Illumination
  - Monochromatic: 635, 785, 809, and 835 nm wavelengths
  - 2, 10, and 20% BW around 800 nm center
  - Medium and high power super-continuum sources
- Low-Noise ($5e^-$) CCD camera, 13 μm pixels
- Complete computer control with data acquisition and storage
- Safe and convenient optical table installation/removal
- Coronagraph model validation & error budget sensitivities
- Remote access through FTP site



HCIT-1 single-testbed capacity (5'x8')



HCIT-2 Two-testbed capacity (6'x10')



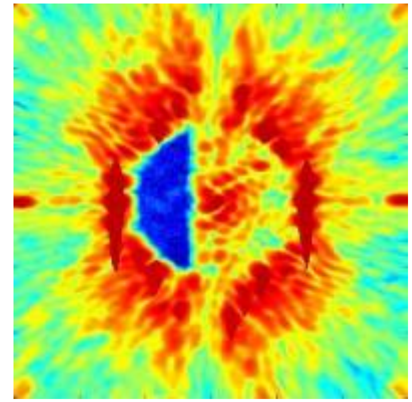
HCIT-1 with Hybrid Lyot coronagraph

Availability expected beginning of FY17

Wavefront Sensing & Control

Nulling Algorithms

- Electric Field Conjugations (EFC) algorithms exist for single and dual DM control
- Demonstrated to < 10^{-9} contrast and 20% bandwidth
- Coupled to HCIT coronagraph models and DM calibration data for optimal efficiency



Best Results to Date

***Band-Limited Coronagraph* :**
6 e-10, @ 3 λ/D with 10% BW
2 e-9, @ 3 λ/D with 20% BW

***Shaped-Pupil Coronagraph*:**
1.2 e-9, @ 4 λ/D with 2% BW
2.4 e-9, @ 4 λ/D with 10% BW

***PIAA Coronagraph*:**
<1e-9, @ 2 λ/d with 0% BW

***Vector Vortex Coronagraph*:**
<1e-9, @ 3 λ/d with 0% BW

EFC Nulling and current performance

Deformable Mirrors

- **Wavefront control and speckle nulling available with Xinetics PMN deformable mirrors.**
  - Format sizes: 32x32mm, 48x48, and 64x64 mm with 1 mm pitch and 500 nm stroke size.
  - Continuous fuse silica facesheet polished to λ/100 rms
  - Two-DM configurations available
- **Boston Micromachines MEMs DMs available in 2016**
  - Continous facesheet mirrors w/ 1020 actuators

Xinetics Deformable Mirrors

Xinetics DM

Coming in 2016

- Dynamic Perturbations Simulator
- Low Order Wavefront Sensor
- Modelable testbed

Availability expected beginning of FY17

Available Resources at JPL for TDEM-14

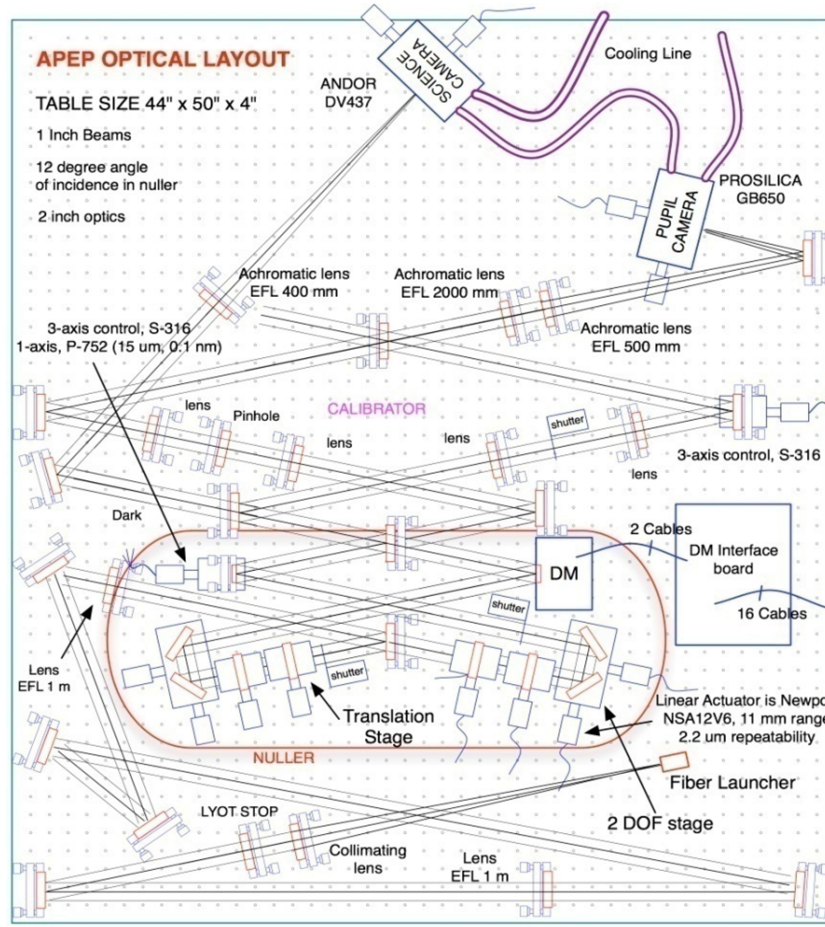
Small Vacuum Chamber (Apep)

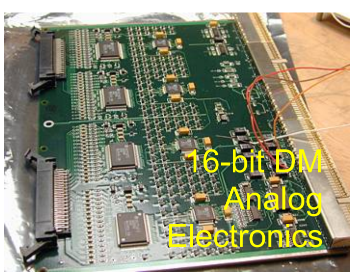
Currently used for Visible Nulling Coronagraph
- Optical layout as shown on the right
- Includes segmented BMC DM, pupil, and science cameras

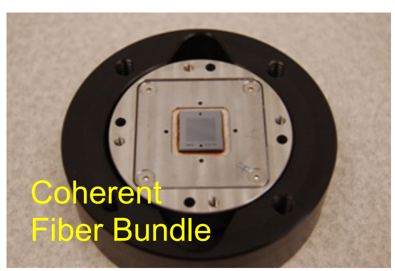
16-Bit DM Electronics for Vacuum
- Minimizes feed-throughs into vacuum tank
- Designed for Boston Micromachines segmented DM
- Conductively cooled electronics and chassis

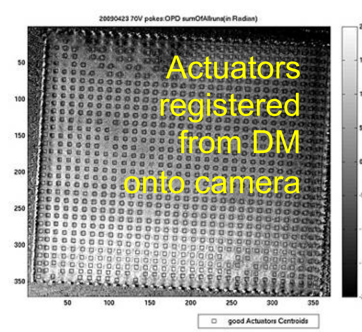
Coherent Fiber Bundle and Lens Array
- Prototype of 217 fibers, with map of fiber positions
- Fiber bundle and lenslet array now integrated
- System performance demonstrated

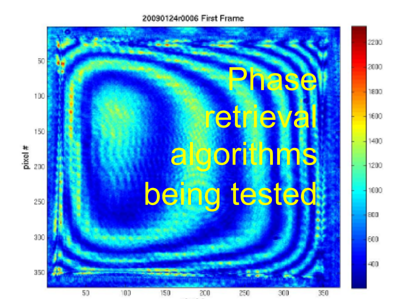
Control System Based on RTC
- Real-time phase retrieval demonstrated
- DM control better than 5nm







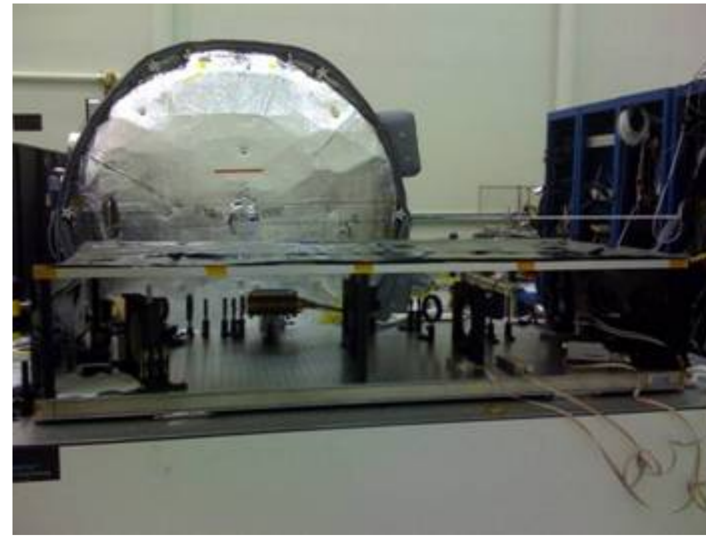




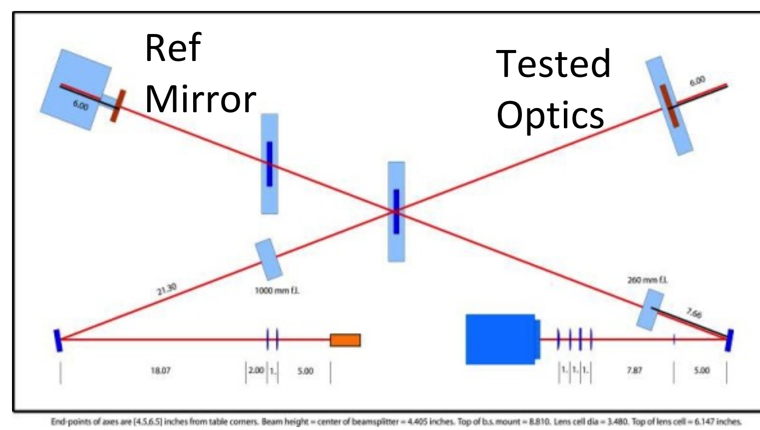
Vacuum Surface Gauge

Purpose: Accurate wavefront measurement and deformable mirror calibration.

- **Customized Michelson interferometer set-up**
  - Reference mirror w/ absolute position feedback
  - Frequency stabilized laser source
- **Camera pixel size: 100 microns equiv. on surface to be measured**
- **Dedicated algorithms for wavefront extraction over > 10^6 pixels**
- **Demonstrated optical surface measurement accuracy: < 1 nm rms**
- **Can operate in vacuum within HCIT lower level or separate testbed**
  - Concurrent measurement with other coronagraph experiments



Surface Gauge bench fits into lower mezzanine of HCIT



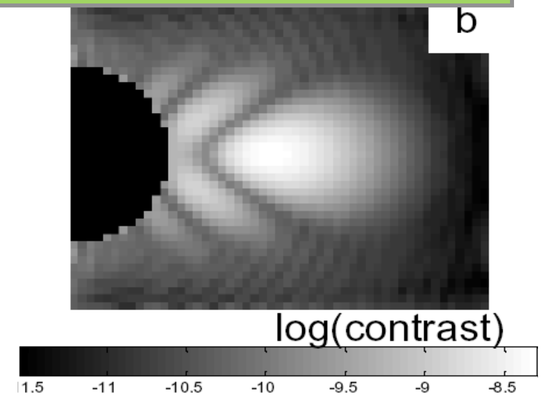
Surface Gauge optical layout

Coronagraph Modeling & Error Budgets

Purpose: (1) Specifying milestone performance goals tied to flight missions and (2) defining testbed error budgets and sensitivities for model validation

Coronagraph Modeling

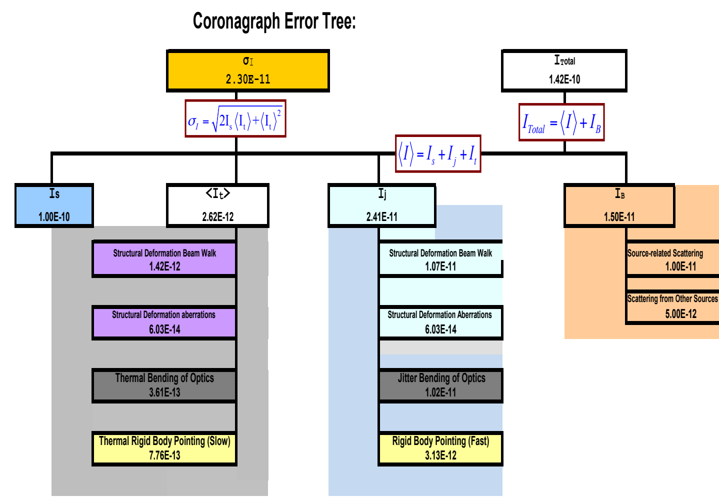
- **Multiple models and tools are available:**
  - Optical diffraction tools with Fresnel propagation and active wavefront control for simulations of broadband contrast performance
    - Includes mask transmission errors, alignment & optical figure errors, nulling algorithms w/ deformable mirror influence functions
    - Coronagraph propagation models are available
  - Mission simulation, orbit determination, spectra characterization



PIAA residual image after DM correction (Shaklan SPIE 2007)

Generalized Error Budget Tool

- **Automated error budget tool for any internal coronagraph system:**
  - observatory tolerances to back-end contrast
- **Integration of Matlab-code and Excel macros for rapid prototyping**



Coronagraph Error Budget Tool Screenshot

Microdevices Laboratory (MDL)

Purpose: Precision sub-micron materials fabrication and characterization

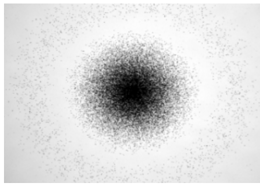
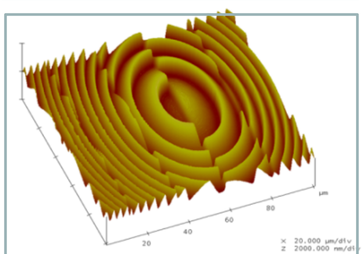


Figure 1. Microscope image (above) and AFM profile (below) of a micro dot patterned mask for JWST NIRCam coronagraph



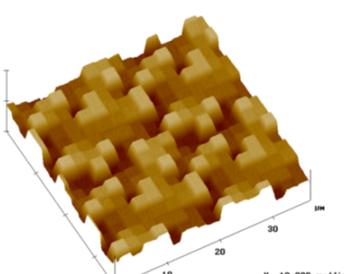


Figure 2. Diffractive optical devices

Advanced fabrication and characterization techniques

- Electron Beam Lithography
- Deep Reactive Ion Etching
- ICP Cryo Etching of Black Silicon microstructures

- Scanning Electron Microscopy
- Precision Optical Microscopy
- Atomic Force Microscopy
- 2D and 3D profilometry

Light suppression mask fabrication processes developed for:

- Micro dot patterned mask for JWST (Fig 1)
- Diffractive optical structures for spectrometer gratings and other computer generated holograms (Fig 2)
- Shaped pupil masks with fine structures and slits for transmission geometry (Fig 3)
- Shaped Pupil masks with black silicon structures in reflective aluminum background (Fig 4)
- LOWFS masks (Fig 5) incorporating a black silicon region (Fig 6) as well as shaped aperture through a silicon wafer
- Achromatic focal plane masks with deep diffractive structures (Fig 7)
- Micro slits for fabricating Hybrid Lyot coronagraph masks
- PIAACMC mask (Fig 8, a proposed design)
- Hybrid Lyot mask for AFTA (Fig 9, a proposed design)

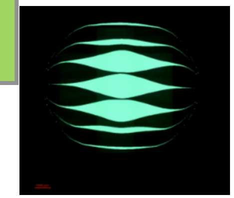


Figure 3. Transmissive slit SP mask

Figure 4. Reflective and absorptive SP mask

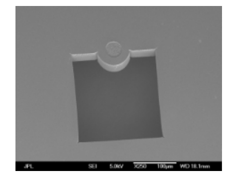


Figure 5. LOWFS mask

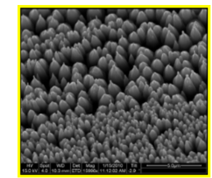
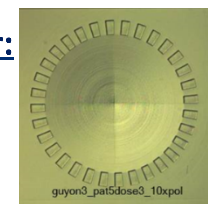


Figure 6. Black Si Microstructure



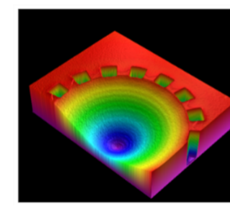
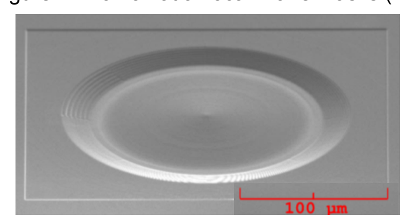


Figure 7 . Achromatic Focal Plane Masks (AFPM)



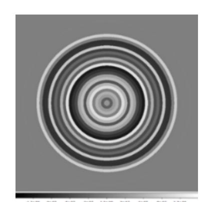


Figure 8 . PIAACMC mask

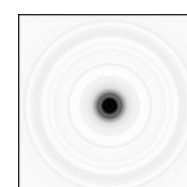


Figure 9 . Hybrid Lyot mask

Starshade Deployment Testbed (*new*)

Purpose: Enable maturation of key starshade deployment components

- **Testbed Description**
  - 10m motorized deployable starshade inner disk from 1.5m stowed configuration
  - Gravity compensation fixtures
  - Flight-like perimeter truss
- **Starshade Technology Opportunities**
  - Petal blanketing, inner disk blanketing
  - Petal unfurling mechanism
  - Launch latching
  - Micrometeoroid testing

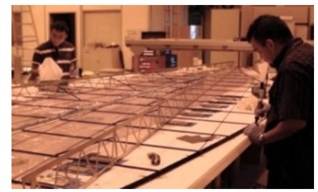
See 2015 ExEP Technology Plan Appendix: http://exep.jpl.nasa.gov/technology/

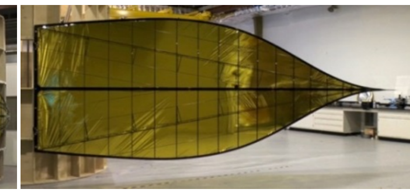
Advanced Large Precision Structures Lab

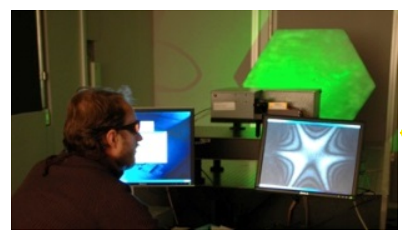
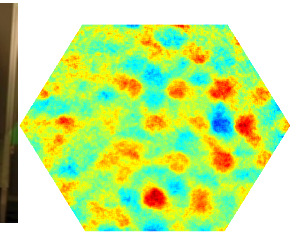
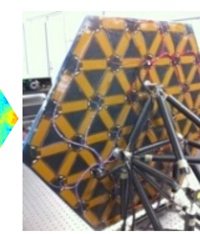
Purpose: Laboratory for demonstrating accuracy and stability of large deployable structures

Facility

- **Dimensions: 10m x 5m x 3m**
- **Stable testing environment**
  - Thermal stability: < 0.01 K/hr, < 0.02 K/24 hr
  - Vibration: < 75 u-g rms (0-500 Hz)
  - Acoustics: 35 dbA
  - Relative humidity stability: 1%
- **Active thermal control**
  - < 5 min for air temp stabilization (30 min from cold start)
  - Up to 1 kW heat load while maintaining performance
- **Class 100,000 clean room capable**
- **Wall and ceiling mounting possible**





Measurement Capabilities

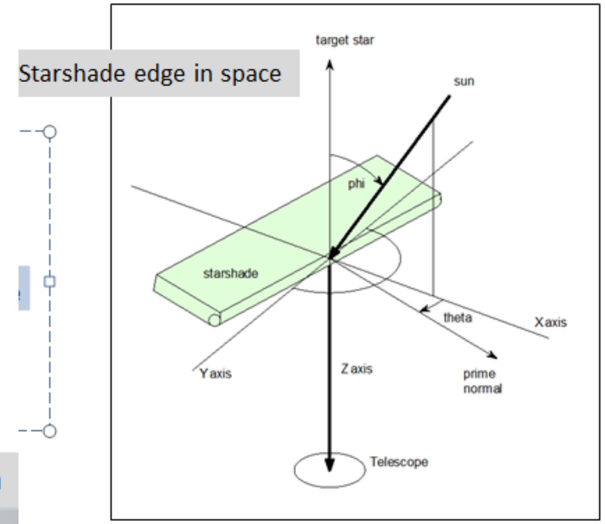
- **Scanning laser vibrometer**
- **Labview data acquisition and control**
  - 60 high-speed simultaneous sampling for accelerometers
- **Laser holography system for in- or out-of-plane deformations of 10 nm to 25 um.**
- **Videometry for < 0.5 mm measurements at up to 16 frames/s for 20 min**
- **FLIR thermal imaging camera, modal test exciters**

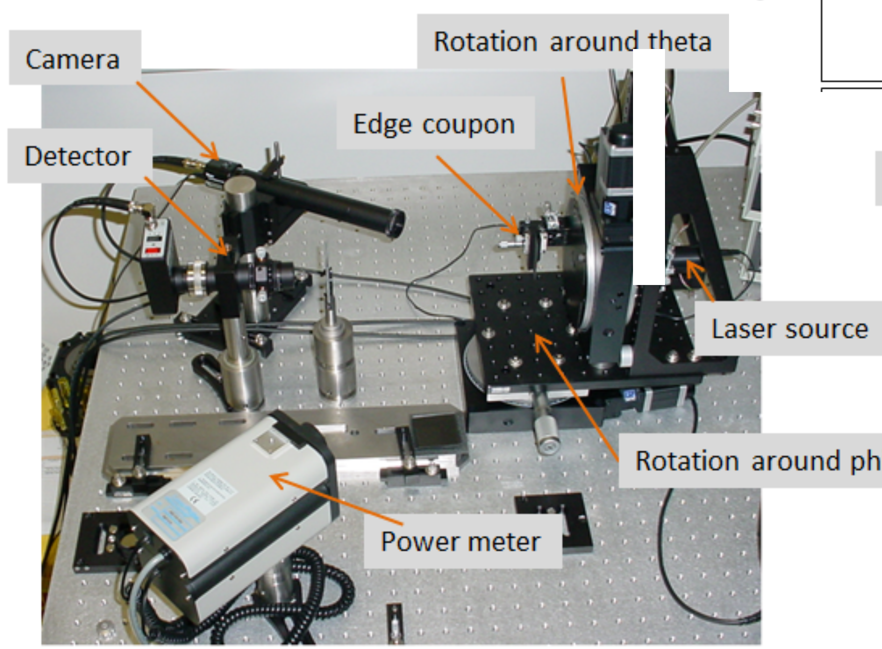
Scatterometer

Purpose: measurement of light scatter from material coupons

Scatterometer Testbed

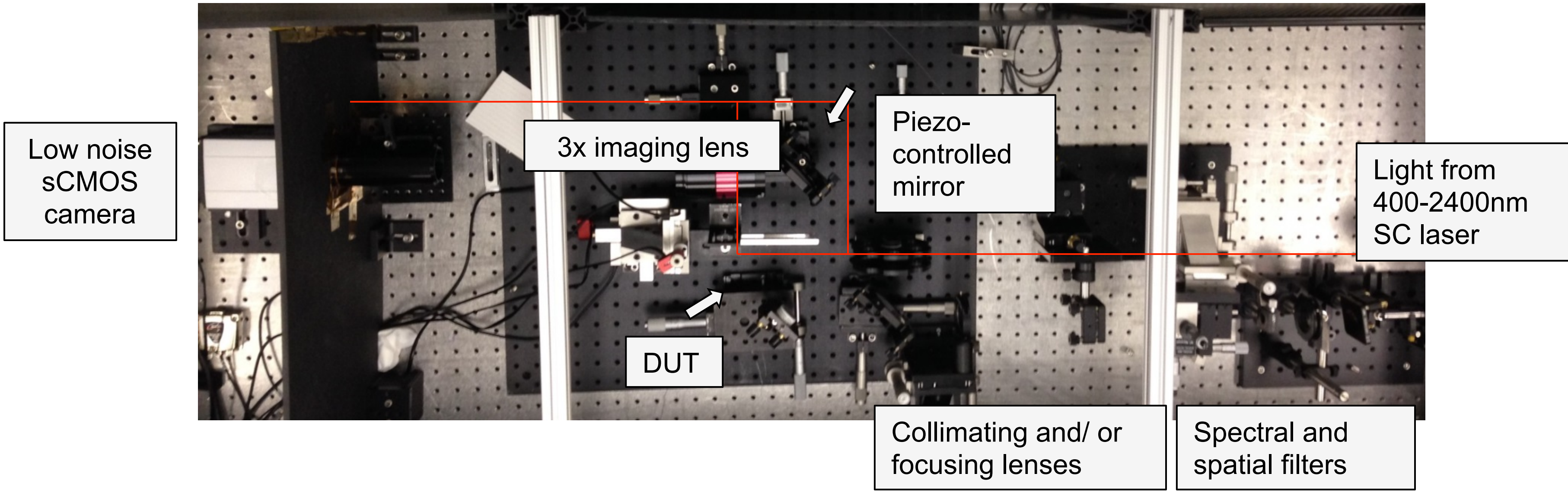
- Accurate for both specular and diffuse scatter
- Measures down to ~10^{-23} W/m^2 equivalent in space
- Optical chopping eliminates background light
- Separate measurements for s and p polarizations





Mach-Zehnder Interferometer

Purpose: characterize transmissive coronagraph mask phase and amplitude transmission



- Can be used for characterizing any transmissive coated or uncoated mask
- Attractive for characterizing high optical density (OD) masks due to single-pass optical propagation
- Diffraction-limited spatial resolution of ~3 um
- Can handle masks up to ~1''x1''
- Option of collimated illumination (for faster characterization) or scanned focused illumination (for characterizing masks with great OD variation). Latter capability still under development.
- Data acquisition and processing largely automated
- Presently set up for air testing only

Gaining Access to the ExEP Resources at JPL

How to Request Use of ExEP Resources at JPL

- **Submit preliminary Statement of Work (SOW) for use of ExEP resources to Nick Siegler no later than March 3, 2015.**
  - Follow SOW questionnaire on next page.
- **Schedule telecon with Nick Siegler between March 3 – 10, 2015 to discuss use of the resources of interest and to obtain costing guidelines.**
- **Nick Siegler will evaluate workforce, labor, and infrastructure access required across all received SOWs.**
  - Assessment will be provided to Doug Hudgins for consideration in proposal review process.
- **Nick Siegler will supply the proposal PI a Letter of Commitment for use of any ExEP resources.**
  - PIs are to include both the SOW and the Letter of Commitment in their proposal.

SOW Questionnaire for Use of ExEP Resources

1. **Brief description of the proposed TDEM**
2. **What resources is requested?**
3. **Milestone (s) to be accomplished and performance goals**
4. **Brief description of how the work will be conducted**
5. **Period(s) and preferred dates over which the resource is requested, stating whether in vacuum or air for testbeds. Include any time required for preparatory work.**
6. **A list of the personnel, expertise, and level of effort (if any) who will assist in the use of the resource.**
7. **Any anticipated changes to the resource needed to accommodate your demonstrations.**
8. **List of items needed for all testbed modifications. Identify items you will be procuring within your proposal's budget and provide approximate cost of needed items.**
    a. Otherwise, state that no additional procurements will be necessary for the use of the infrastructure under consideration.
9. **Provide any other relevant information or constraints.**

How to Cost the Use of ExEP Resources at JPL

- **Some base funding is provided for access to ExEP resources at JPL. However, additional labor and procurements specific to your proposal must be costed within the proposal to support the work:**
  - Directly funded through the proposal (PI-managed JPL labor & procurements)
  - Request additional resource support through the Program (ExEP managed labor and procurements)
  - In either case the PI remains responsible for leading the demonstrations

ExEP Technology Resources POC

For questions concerning use of ExEP technology resources or requests for more detail contact:

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